ALIGNMENT INSTRUCTION

MARINE PROPULSION

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WIN GD

ALIGNMENT INSTRUCTION

MARINE PROPULSION

PC-Drawing

Dimension: MARINE PROPULSION

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List of Abbreviations

3D: three-dimensional
ALC: alignment layout calculation
CPP: controllable pitch propeller
DG: design group: WinGD structure of engine drawing set
EnDyn: WinGD program for calculating alignment
FE: finite elements
FPP: fixed pitch propeller
free end PTO: generator driven by the forward end of crankshaft
fwd: forward (ahead or bow side of vessel)
mb: engine main bearing
TDC: top dead centre, turning position of a crank with its pin in vertical upward position
TVC: torsional vibration calculation
TV damper: torsional vibration damper
VLCC: very large crude carrier
VLOC: very large ore carrier

1 Introduction and overview

The installation and alignment of the propulsion shafts and main engine are the responsibility of the shipyard. It ensures the following for all ship operating conditions:

1. static bearing loads within the limits
2. angular alignment of the propeller shaft inside the aft stern tube bearing bore within the limits
3. crank web deflections within the limits.

To fulfil the above-mentioned requirements, the factors influencing alignment need to be considered adequately, like for instance operating forces and temperatures as well as elastic ship hull bending.
The alignment of the propulsion shafts and main engine is carried out according to a case-specific alignment layout calculation (ALC), and compliance with this is verified by measurements.

1.1 Alignment documentation

The WinGD alignment documentation contains:

1. instructions, providing limits and requirements to comply with
2. recommendations and guidelines, given for reference, to support in achieving compliance with the requirements and limits.

1.1.1 Instruction

1.1.1.1 Validity

This instruction applies to installation of the WinGD low-speed engines in direct-coupled marine propulsion plants.

1.1.1.2 Content

This instruction contains the following information and data:

1. introduction and overview[1]
2. crankshaft models[2]
3. static main bearing loads[3]
4. crank web deflections[4].

1.1.2 Guidelines

1.1.2.1 Validity

The guidelines and recommendations are given for reference to guide the persons responsible for design, manufacturing and installation of the marine propulsion plant(s).
The guidelines apply to standard designs of direct-coupled marine propulsion plants, comprising:

- two stern tube bearings, white metal type
- one or more intermediate bearing(s), arranged at a minimum distance of $0.5 * 450 * \sqrt{Ø_{\text{shaft(mean)}}}$
- no shaft generator (PTO), no shaft motor (PTI) or similar shaft-mounted components.

Other designs are supported according to section *1.2*.

[1] Successor of DAAD040460- ‘Introduction’, DAAD040461- ‘Alignment in brief’ and DAAD040465- ‘Measurements during normal ship service’.
[2] Successor of DAAD040463- ‘Equivalent two-dimensional crankshaft model’.
[3] Successor of DAAD040467- ‘Main bearing loads – recommendations and limits’.
[4] Successor of DAAD040466- ‘Crank web deflections - limits’.

1.1.2.2 Topics

The following guidelines are issued in addition to this instruction and are provided on WinGD web page:

1. *DAAD040462 'Guidelines for Layout Calculation'*
2. *DAAD040464 'Guidelines for Alignment Process'*
3. *DAAD040468 'Guidelines for Measurements'*.

1.2 WinGD support

1.2.1 Case-specific alignment support

WinGD provides case-specific alignment support. This includes for instance:

1. checking the arrangement of shaft bearings according to section 1.3.1.1
2. assistance in creation of ALCs including recommendations for appropriate case-specific static load distribution of main bearings
3. review of alignment layout calculations
4. support during installation, including evaluation of measurements according to section *1.2.5.*

If a new ship is built and propelled by WinGD engines, this service is free for the shipyard and our licensee.

1.2.1.1 Scope of WinGD alignment support

WinGD provides support for alignment if the ship building follows usual procedures and also if the alignment of the shafts and the main engine is performed according to the usual procedures (see section *1.3.2*), in continuous and completely floating state.
Otherwise, detailed information and data about the influence on alignment is required.

Alignment in dock or on slipway

Carrying out the complete alignment processes already in the dock or on the slipway lies within the responsibility of the shipyard. WinGD has no objection to this.
Alignment measurements are evaluated on request. However, for the confirmation of the engine alignment, WinGD requires the exact offset change values for each bearing.
Alternatively, WinGD can evaluate and confirm engine alignment based on measurements taken once the vessel is floating.

Alignment in partly floating conditions

If the ship hull touches the ground continuously or occasionally (e.g. if the ship floating condition depends on the tide), then the ship hull bending differs to an unknown degree compared to the required fully floating condition. For such conditions, WinGD cannot provide support for alignment.

1.2.2 Application 'EnDyn' for alignment calculation

The EnDyn application for alignment calculations of engines is provided free for our licensees. It can be ordered by e-mail at: *TechLicSupport@wingd.com*.

1.2.3 Creation of alignment layout calculations (ALC)

WinGD offers complete ALC (packages) as a billable service.
A questionnaire to supply inputs for shaft calculations (TVC, ALC, etc.) is provided on WinGD web page: *questionnaire for shaft calculations*.

1.2.4 Spreadsheets for recording and evaluation of measurement results

A spreadsheet in Microsoft Excel file format for recording and evaluation of crank web deflections as well as jack-up test results for shaft and engine main bearings is provided on WinGD web page: *engine alignment record sheets*.

1.2.5 Evaluation of alignment measurement results

WinGD evaluates measurement results for crank web deflections and static bearing loads.
Depending on the result, WinGD

- either issue a confirmation for the engine alignment
- or give detailed recommendations for re-adjustments.

If a new ship is built and propelled by WinGD engines, this service is free for the shipyard and our licensee.

1.3 Alignment during a new ship build

This section gives an overview of shaft and engine alignment for a new ship build project.
Detailed information can be found in the mentioned guidelines.

1.3.1 Project and design stage

Detailed information on this subject is given in *DAAD040462 'Guidelines for Layout Calculation'*.

1.3.1.1 Checking for sufficient shaft bearing distances

It is strongly recommended that the shaft bearings are arranged with the required sufficient distances.
It eases alignment during installation and results in safe static loads at low variations.
Recommendations are given in the above-mentioned guideline.
Additional support is given according to section *1.2*.

1.3.1.2 Alignment layout calculation (ALC)

A design-specific ALC must be done in good time before production of the propulsion shaft line components begins. The ALC determines mainly:

1. the static loads and the offsets of the bearings
2. the required slope machining of the aft stern tube bearing bore, which is required to meet the very stringent limitations of the maximum allowable angular misalignment to the propeller shaft
3. the alignment data for the shafts and the main engine during their installation.

1.3.1.3 Complying with permissible epoxy resin chock heights

The WinGD design of engine fixation parts (foundation bolts, thrust sleeves, side stoppers) covers a certain range of the permissible heights of the main engine epoxy resin chocks. For further information, please refer to DG 9710 'Engine seating / foundation'.
To achieve epoxy resin chock heights within this permissible range, it is necessary to carefully determine the height and the inclination of the stern tube in relation to the engine foundation, taking into account:

1. the bearing offsets obtained by the ALC[5]
2. the elastic ship hull bending[6]
3. the height of engine main bearings[7]
4. the engine-specific design height of epoxy resin chocks.

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5 The ALC determines the offsets of stern tube and engine main bearings for afloat condition.
6 Elastic ship hull bending varies the bearing offsets from dry-dock / slipway to afloat condition.
7 Given in column 'h_{mb}' of *Table 2-1 'Equivalent two-dimensional crankshaft model data'*, on page *16*.

1.3.2 Alignment during installation

Detailed information on this subject is given in *DAAD040464 'Guidelines for Alignment Process'*.

1.3.2.1 Principle

Alignment of propulsion shafts to the stern tube

The propulsion shafts and the main engine are aligned in relation to the stern tube and its bearing(s):

1. The adjustment of the vertical offsets according to the ALC results in a curved bending line of the shafts in the vertical plane (side view).
2. In the horizontal plane (top view), the shafts and the main engine must be aligned to a straight line – except if defined differently by the ALC.

Alignment of main engine to the propulsion shafts and to the foundation

The crankshaft is aligned to the forward end of the propulsion shafts.
The bedplate is aligned to the integrated foundation top plate of the ship hull.

1.3.2.2 Basic alignment process

Before floating of the vessel, the propeller shaft including propeller and the stern seal(s) are installed.
After floating of the vessel, alignment is continued as follows:

1. The proper alignment of the propeller shaft to the stern tube bearing(s) is ensured.
2. The un-coupled intermediate shaft(s) and the main engine are aligned to the propeller shaft.
3. Alignment in fully coupled condition of all shafts and the main engine is checked.

If alignment complies with the ALC, then the main engine and the intermediate bearings are chocked and fixed to their foundation.
Otherwise, corrective measures are applied, and the checks are repeated.

1.3.2.3 Alignment of un-coupled shafts

This method was developed to enable the adjustment of offsets of the intermediate bearing(s) and the main engine in relation to the stern tube bearing(s) in floating condition, i.e. with propeller shaft and propeller already installed.

Principle

For aligning an un-coupled shaft (or a pre-coupled shaft section), the latter is positioned on only two supports, each in the shape of either an intermediate bearing or a temporary support.
The longitudinal positions of the supports comply with the ALC.
Then these two supports are adjusted until the aft flange of the shaft (or the pre-coupled shaft section) to be aligned has the following position to the counter flange of the previously aligned aft shaft:

- equal horizontal gap and equal horizontal sag values on both sides
- vertical gap and vertical sag values according to the ALC.

Alignment of un-coupled propeller shaft (before floating)

The propeller shaft including the propeller, its nut and its cap as well as the stern tube seals are installed.
If indicated by the ALC, accordingly (position and force) a jack-down force must be applied at the forward part of the shaft, to exclude a bottom clearance in the forward stern tube bearing.
The propeller shaft alignment to the stern tube bearings is measured, to provide a reference for rechecking after floating.

Alignment of un-coupled intermediate shaft(s) (floating condition)

The installation and alignment of shafts is carried out progressively from aft to forward:

1. Firstly, the alignment of the propeller shaft to the stern tube is ensured by referring to the above-mentioned reference measurements made before floating.
2. Subsequently, the intermediate shaft is aligned to the propeller shaft.
   In case of several intermediate shafts:
   a. The aftmost intermediate shaft is aligned to the propeller shaft first.
   b. Then the second-aftmost intermediate shaft is aligned to the aftmost one.
   c. This is continued progressively for each additional intermediate shaft until also the foremost intermediate shaft is aligned to the second-foremost one.
3. Finally, the main engine is aligned to the (foremost) intermediate shaft.

1.3.2.4 Alignment of un-coupled main engine (floating condition)

The main engine must be aligned according to two aspects:

1. The crankshaft is aligned to the forward end of the propulsion shafts according to the ALC.
2. The main engine bedplate is aligned to the foundation:
   a. straight in the horizontal plane and
   b. straight or smoothly bent according to section *1.3.2.5* in the vertical plane.

Adjustment of height and inclination of the main engine is done by means of the full number of jack screws (or alignment wedges), according to the engine-specific drawings of DG 9710-01 - 'Tool engine alignment'.

1.3.2.5 Bedplate bending / crankshaft sag

WinGD engines can be aligned so that they have a straight bedplate at light ballast or ballast draught. Alternatively, WinGD engines can also be aligned to show a very slight bed plate bending / crankshaft sag according to formula (1-1) below.
A bed plate bending must be smooth, and it must be approximately same on the port and starboard side.

$$bedplate\ bending = cylinder\ bore\ size\ [cm] * cylinder\ number * \frac{engine\ sag\ factor}{1000}\ [mm] \quad (1\text{-}1)$$

Engine sag factors:
Ø35 to Ø72 cm bore size engines: -0.4
Ø82 to Ø92 cm bore size engines: -0.7

The crank shaft sag value can be concluded from the crankshaft bending lines, illustrated in the web deflection records of the WinGD spreadsheets for ship alignment measurement results (see section *1.2.4*).

Short small-bore engines with heavy load at the crankshaft forward end

A hogging bedplate / crankshaft up to approx. 0.2mm is recommended if a heavy[8] TV damper or front disk (tuning wheel) or similar, acts at the crankshaft forward end flange of 5- and 6-cylinder engines of Ø35 to Ø72 cm bore size.

1.3.3 Alignment measurements

Detailed information on this subject is given in *DAAD040468 'Guidelines for Measurements'*.

8 A component attached to the crankshaft forward flange is designated as heavy, if it's mass amounts minimum 70 per cent of the engine-specific mass force 'Fc' (listed in *Table 2-1*).

1.3.3.1 Alignment measurement types

The following types of measurements are common to check the alignment of direct-coupled propulsion shaft lines:

Gap and sag of un-coupled shafts

These measurements are applied to check the alignment of a shaft to the next rear shaft before they are coupled together. The measurements are carried out on the two opposing opened flanges of both shafts:

- The gap (angular offset) between the two flanges is measured to check the inclination of the shaft to be aligned to the next rear shaft.
- The sag (radial offset) of the two flanges is measured to check the radial misalignment of the shaft to be aligned to the next rear shaft.

Crank web deflections

This measurement is used to check the alignment of the crankshaft.
The change in distance between the end faces of both main bearing journals of each crank within nearly one revolution is measured by means of a dial gauge.

Static bearing loads (jack-up tests)

This is the usual method applied to determine the static loads of sleeve bearings.
A hydraulic jack to lift the shaft is arranged next to the bearing; a dial gauge is installed for measurement.
The change of jacking force and the resulting change in vertical shaft offset are recorded during lifting and lowering of the shaft and plotted as a lifting and a lowering curve.
The evaluation of these two curves delivers the mean jacking force.
The static bearing load is calculated from the product of the mean jacking force and the jack correction factor (see section *3.5.1*).

1.3.3.2 Alignment checks during installation

Alignment in fully coupled condition of all shafts and the main engine is checked by measuring static bearing loads and crank web deflections upon reaching the following ship building progress:

1. before chocking of the main engine (required)
2. after chocking and fixation of the main engine (optional) [9]
3. at ship commissioning / delivery (optional, during or after sea trial).

1.4 Alignment checks in normal ship service (after ship delivery) [10]

In normal ship service, regular recordings of the crank web deflection are required in accordance with the Instruction Manual (IM).
The measurements made at ship commissioning / delivery as well as the regular recording of crank web deflections in normal ship service serve as reference for each additional measurement.
In cases of irregularities or damage or repair, enhanced alignment measurements can be needed, of which the type and scope depend on the incident, observation and risk.
To ensure the efficiency of such enhanced alignment measurements, it is recommended that they are clarified in advance and in detail with WinGD, independent of the company performing them on site.

[9] Carrying out these optional measurements before chocking of the intermediate bearing(s) provides the possibility of small corrections before they are also chocked and fixed.
[10] The contents of this section and of the engine-specific Instruction Manual (IM) replace the previous document DAAD040465 ‘Measurements during normal ship service’.

2 Crankshaft models

WinGD has introduced 'short-stroke' engine types X52*-S and X62*-S.
For X62*, X72* and X92* engines crankshaft variants with shorter distances between the crankshaft aft end flange and aftmost cylinder 1 have been introduced.
Also the design of flywheel, DG 3122, and of the crankshaft aft end flange diameter and bolting, DG 3114, may vary.

IMPORTANT:
Check carefully and make sure that all below-mentioned drawings which will be used for the same ship building project contain the same distance between the aft crankshaft flange and the centre of the aftmost cylinder 1:

1. in the case-specific shaft arrangement drawing
2. in the relevant WinGD engine outline drawing, DG 0812
3. in the relevant WinGD crankshaft machining drawing, DG 3106
4. in the case-specific torsional vibration calculation (TVC)
5. in the case-specific alignment layout calculation (ALC).

2.1 EnDyn program integrated 3D FE based crankshaft models

Figure 2-1: 3D crankshaft model including running gears plus flywheel

Realistic three-dimensional finite element (3D FE) based crankshaft models of the current WinGD low-speed engine portfolio are contained in the WinGD EnDyn calculation program.

They can be easily retrieved by a single command line, e.g.
a seven-cylinder X82 dual-fuel methanol engine,
with crank type “fcv2”, i.e.:
7X82DF-M-1.0, fcv2:

EnDyn input:

```
crankshaft=([aft end node],[forward end node])
name=”7x82df-m-1_fcv2”
```

These EnDyn incorporated 3D FE based models of complete crankshafts comprise:

1. the thrust shaft, the main bearing journals and the full number of cranks, each as 3D FE based model, arranged at corresponding crank angle
2. the mass loads of:
   a. the aft and the forward end flange
   b. the thrust collar
   c. the running gear attached on each crank, i.e. piston, piston rod, cross head and connecting rod
   d. the gearwheel attached on crankshaft
3. the main bearings, including:
   a. clearance
   b. bearing support stiffness
   c. bearing support height
4. the thrust bearing eccentricity.

2.1.1 Varying crank angle-dependent stiffness

The EnDyn incorporated 3D FE based crankshaft models consider the varying crank angle-dependent stiffness of the three-dimensional cranks.
This is the pre-requisite for calculating correct static loads for all engine main bearings.
For further information, please refer to *DAAD040468 'Guidelines for Measurements'*.

2.1.2 Consideration of the flywheel, a front disc or a TV damper and/or a free end PTO drive

1. The mass of the case-specific flywheel must be added at the crankshaft aft end flange.
   The case-specific flywheel is determined by the torsional vibration calculation (TVC).
2. The same is recommended for the crankshaft forward end flange, if a front disc (tuning wheel) or a TV damper and/or a free end PTO drive is attached there.
   In view of the static load reduction of the second-foremost main bearing (mb #(n-1)), it must be observed that the recommended minimum static loads apply to the entire rotation.

2.2 Equivalent two-dimensional crankshaft model

2.2.1 Application

Equivalent two-dimensional[11] crankshaft models are provided for calculating alignment with applications other than the WinGD EnDyn.
The WinGD equivalent two-dimensional crankshaft models deliver just the calculated static loads for the three aftmost engine main bearings (aftmost mb #1, mb #2 and mb #3) only, even if the model is extended with additional main bearings.
The following deviations occur compared to the results achieved by means of the EnDyn integrated 3D FE-based models, when the aftmost crank #1 is at top dead centre (TDC):

- about 5% for aftmost mb #1 and mb #2
- about 10% for mb #3, or even more in some special cases.

IMPORTANT:
The structure of the equivalent two-dimensional crankshaft model must comply with *Figure 2-2 below*.
Each dimension (lengths, diameters) and property (mass forces, main bearing stiffness, etc.) must comply with relevant data given in *Table 2-1 below*.
Consequently, the engine main bearings must be considered with the given support stiffness.
Omission or deviation from the above-mentioned causes invalid calculation results.

2.2.1.1 Restrictions

Further results that the calculation can yield for the two-dimensional crankshaft model in addition to the above-mentioned, like static loads for main bearings mb #4 and mb #5, bending stress, etc. are not realistic and therefore cannot be evaluated.

[11] The elements of the calculation model are composed just on two axes: horizontal (lengths) and radial (diameters).

2.2.2 Construction

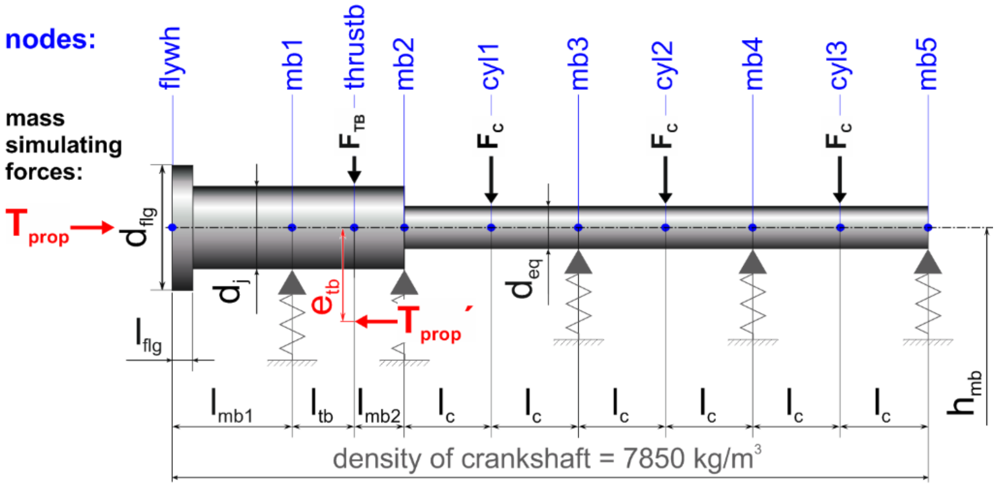

Figure 2-2: Equivalent two-dimensional crankshaft model

WinGD equivalent two-dimensional crankshaft models consist of the following elements:

1. aft coupling flange and thrust shaft with a density of 7850kg/m^3
2. cylinders of similar stiffness in the range of the three aftmost cranks with a density of 7850kg/m^3
3. force F_{TB} to simulate the masses of thrust collar and gear wheel[12]
4. force F_C to simulate the masses of cranks and running gears
5. elastic main bearings with clearance
6. thrust bearing eccentricity.

[12] In case of X92 engines with 2-part crankshafts, the gear wheel on crankshaft is arranged further forwards between the cranks. Therefore Table 2-1 shows lower 'F_{TB}' values for those engines.

2.2.3 Data table

Table 2-1: Equivalent two-dimensional crankshaft model data

Contact WinGD (TechLicSupport@wingd.com) in case of questions about an engine type.

Length / Diameter / Force / Stiffness			l_{flg}	d_{flg}	l_{mb1}	d_j	l_{tb}	l_{mb2}	d_{eq}	l_C	F_{TB}	F_C	h_{mb}	e_{tb}	Bearing stiffness	Bearing clearance
Engine	Var.	Cyl.	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[N]	[N]	[mm]	[mm]	[N/m]	[mm]
X35 X35-B		5 – 8	100	695	320	430	285	155	220	306	7000	33000	830	-86	4 E9	0.28
X40 X40-B X40DF X40DF-1.0		5 – 8	115	816	370	490	325	175	255	350	10000	49000	950	-98	4 E9	0.28
RT-flex50-D RT-flex50DF		5 – 8	120	970	456	600	345	211	328	440	16000	93000	1088	-120	4 E9	0.35
X52-S2.0 X52DF-S1.0 X52DF-S2.0 X52DF-M-S1.0	short stroke	5 – 8	155	1005	485	640	301	193	330	430	19000	102000	1186	-128	5 E9	0.33
X52 X52-1.1 X52DF X52DF-1.1 X52DF-2.1 X52DF-A-1.0		5 – 8	155	1005	505	640	370	285	350	470	21000	115000	1205	-128	5 E9	0.33
RT-flex58T-E		5 – 8	150	1108	520	706	367.5	237.5	375	503	23000	138000	1300	-141	5 E9	0.40
X62-S2.0 X62DF-S1.0 X62DF-S2.0 X62DF-M-S1.0	short stroke	5 – 8	180	1175	514.5	760	355	229	390	500	30000	156000	1295	-152	5 E9	0.40
X62 X62-B X62DF X62DF-1.1 X62DF-2.1		5 – 8	180	1235	625	760	440	357	420	553	39000	180000	1360	-152	6 E9	0.40
X62-1.1 X62DF-1.2 X62DF-2.2 X62DF-A-1.0 X62DF-M-1.0	short thrust shaft, Mk2	5 – 8	180	1175	514.5	760	355	229	420	553	30000	180000	1360	-152	6 e9	0.40
X72 X72-B X72DF X72DF-1.1 X72DF-2.1 X72DF-A-1.0		5 – 8	210	1395	697	880	504	386	470	646	55000	272000	1575	-176	7 E9	0.45

Table 2-1: Equivalent two-dimensional crankshaft model data
Contact WinGD (TechLicSupport@wingd.com) in case of questions about an engine type.

Length / Diameter / Force / Stiffness			l_{flg}	d_{flg}	l_{mb1}	d_j	l_{tb}	l_{mb2}	d_{eq}	l_C	F_{TB}	F_C	h_{mb}	e_{tb}	Bearing stiffness	Bearing clearance
Engine	Var.	Cyl.	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[N]	[N]	[mm]	[mm]	[N/m]	[mm]
X72DF-1.2 X72DF-2.2	*short thrust shaft, Mk2*	5 + 6	210	1395	594.5	880	390	250	470	646	42000	256000	1575	-176	7 E9	0.45
X82-2.0 X82DF-1.0 X82DF-2.0 X82DF-M-1.0		6 – 9	300	1655	657	1060	559	390	565	720	89000	422000	1800	-212	8 E9	0.58
X92-1.1 X92DF-M-1.0	*short thrust shaft, Mk2* *1-part crank-shaft*	6 + 7	265	1835	800	1060	623	417	601	795	94000	523000	1900	-212	8 E9	0.58
X92 X92-B X92DF X92DF-2.0	*1-part crank-shaft*	7 + 8	265	1835	950	1060	633	407	601	795	98000	523000	1900	-212	8 E9	0.58
X92 X92-B X92DF X92DF-2.0	*2-part crank-shaft*	8 - 12	265	1835	956	1120	647	387	606	832	79000	577000	1900	-224	8 E9	0.58

2.2.4 Consideration of the flywheel

The mass of the case-specific flywheel must be added at the crankshaft aft end flange (node 'flywh' shown in *Figure 2-2 above*).
The case-specific flywheel is determined by the torsional vibration calculation (TVC).

2.2.5 Consideration of a front disc or a TV damper and/or a free end PTO drive

The allowable loading at the forward end of the crankshaft must be maintained according to the engine-specific drawing of DG 3128 'Disc / Damper Dimensions'.

2.2.6 Bending moment at engine integrated thrust bearing

The ahead propeller thrust generates an upward-acting bending moment at the engine integrated thrust bearing:

- the propeller thrust acts in the shaft centre
- the reaction force of the thrust bearing acts in the opposite direction below the centre of the shaft, with the offset 'e_{tb}'.

3 Static main bearing loads

3.1 Introduction

Shaft bearings as well as engine main bearings are of sleeve bearing type. They have clearance and require a continuous downward-acting static load for reliable operation:

1. For each shaft bearing a static load with sufficient safety against zero load and against exceeding the maximum load specified by the manufacturer must be ensured.
2. For each engine main bearing a static load complying with the minimum limits of normal ship service given in section *3.9* must be ensured.

The WinGD required minimum static load limits must be maintained for each engine main bearing when the ship is at stopped condition and the propulsion plant is ready for operation.
Meeting this requirement excludes the possibility of an excessive static load for each of the engine main bearings. Therefore, no maximum static load limits are necessary.
To support compliance with the minimum limits of static main bearing loads in normal ship service, WinGD provides recommended static main bearing loads for ALCs and for alignment checks before chocking as well as required static main bearing loads at commissioning / delivery of new ship builds. These data are based on WinGD long-term experience in aligning marine propulsion plants.

3.1.1 Static loads of stern tube and intermediate bearings

Due to the external load of the propeller, the aft stern tube bearing is always well loaded.
The static loads of the forward stern tube bearing and the intermediate bearing(s) are much lower and vary due to the influence of elastic ship hull bending.
Accordingly, these bearings must be carefully adjusted in the ALC, to ensure that the static loads are within the specifications, with sufficient safety margins against zero load and overload.

3.1.2 Static load distribution at the three aftmost main bearings

The main focus of engine alignment is the static load distribution at the three aftmost main bearings.
It is influenced by the design and by the alignment of the direct-coupled propeller and intermediate shafts. These shafts follow the elastic ship hull bending which varies according to the ship draught and trim.
The above-mentioned influences must be considered in the ALC, by pre-compensating for the related changes in static load distribution at the three aftmost main bearings as explained in section *3.2*.
Corresponding recommendations for static main bearing loads are given in section *3.6*.
The successful application of the ALC during alignment before chocking is verified by measurements according to section *3.7*.
These measurements are repeated at ship commissioning / delivery (see section *3.8*).
In normal ship service, static bearing loads are only measured in special/exceptional cases (see section *3.9*).

3.1.3 Static loads at the two foremost main bearings

If there is an external load attached at the forward end of crankshaft, like a front disc (tuning wheel), a TV damper and/or a free end PTO drive, then the static loads of the two foremost main bearings need to be considered as well:

1. During design, this is considered according to sections 2.1.2 item 2 and/or 2.2.5.
2. When aligning during installation, the measurement of static loads at the two foremost main bearings is needed if the threshold value for deviation of vertical web deflections between neighbouring cranks is exceeded at the two foremost cranks #(n) and #(n-1) (see sections *3.3.1.1* and *4.5.3*).

3.1.4 Static loads at the inner main bearings

The static loads of the inner main bearings mb #4 to mb #(n-2) depend on the bedplate alignment as well as on the machining of the bedplate, bearing shells and crankshaft.
Measuring of their static loads is also only required if indicated according to sections *3.3.1.1* and *4.5.3*.

3.2 Influence of elastic ship hull bending

In stopped flat-water conditions, the ship hull bending depends mainly on ship draught and trim as well as on component temperatures.
Regarding the main engine, mainly the three aftmost main bearings and the web deflections of the two aftmost cranks are affected as shown in *Table 3-1*.

Table 3-1: Influence of ship draught on engine alignment

Condition	machinery foundation shape	static main bearing loads		crank web deflection aftmost crank #1
		aftmost mb #1	mb #2	
light ballast draught usual for alignment during new ship build	more sagging or less hogging	↘ reduced	↗ increased	
design to maximum draught	less sagging or more hogging	↗ increased	↘ reduced	

During ship construction, the alignment of the shafts and the main engine is usually carried out in the empty ship and therefore at light ballast draught.
In this condition, the following static load distribution must be adjusted at the three aftmost engine main bearings:

- high static loads at mb #2 and mb #3
- low static load at aftmost mb #1.

3.3 Measurement of static bearing loads

3.3.1 Required set of measurements

Alignment must be checked during installation by carrying out the following set of measurements after coupling of all shafts and the main engine:

1. web deflections of all cranks
2. jack-up tests of the forward stern tube bearing and of each intermediate bearing
3. jack-up tests of the three aftmost engine main bearings, i.e. aftmost mb #1, mb #2 and mb #3.

Jack-up tests for other main bearings, i.e. mb #4 to foremost mb #(n), are needed if the threshold value for deviation of vertical web deflections between neighbouring cranks is exceeded (see section *4.5.3*).

3.3.1.1 Jack-up test basics

Sufficient shaft lifting height

Jack-up tests of engine main bearings must show a shaft lifting height of at least 70% of the main bearing clearance as listed in *Table 2-1*.

Low difference between lifting and lowering jack loads (hysteresis)

Jack-up test results must show a normal hysteresis between the curves of plotted lifting and the lowering jack-up test results.
A normal hysteresis is given, if the lowering jack loads amount approx. 70% of the lifting jack loads at similar shaft lifting heights[13].
A hysteresis of 50% or more is not acceptable.

Sufficient number of jack load measurement points

Jack-up tests must have a sufficient number of measurement points, to obtain a detailed curve for each, when the jack-up test measurement points for lifting and for lowering are plotted.
This is mandatory for a reliable graphical evaluation of the jack load and applies most for jack-up tests of engine main bearings[13].

3.3.2 General measurement conditions

The following conditions apply to all alignment measurements (crank web deflections as well as static bearing loads) in the ship:

1. The ship is floating continuously, no interim change of draught or trim.
2. The main engine is completely assembled, with all pistons and running gears installed as well as all tie rods fully tightened[14].
3. The propeller, the intermediate shaft(s) and the main engine are coupled, supported only by their bearings – any tools or devices for mounting or installing the shafts, such as temporary support(s), jack-down force(s), etc. must be removed.
4. All heat sources in the machinery foundation are switched off in good time before starting each set of measurements according to section *3.3.2.1.*
5. No intermediate changes in the alignment can occur before completion of all measurements of a condition, otherwise the measurements must be aborted and started anew according to section *3.3.2.2.*
6. The ship and the propulsion plant are in a stopped condition.
7. Further conditions apply in addition to the above-mentioned. They are listed for each of the measurement conditions described below.

3.3.2.1 Switching off all heat supplies to the machinery foundation

Any heat supply to the machinery foundation can falsify alignment measurement results, particularly:

1. the heating of the lubricating oil drain tank below the main engine
2. the pre-heater of the main engine lubricating oil separator
3. any other heat source in the double bottom of the engine room.

Each of these heat sources must be switched off in good time before starting measurements and they must remain switched-off until all measurements are completed:

- at least 8 hours before measurements at cold conditions (crankcase temperature less than 30 °C)
- at least 4 hours before measurements at warm conditions (crankcase temperature above 30 °C)
- at least 2 hours before measurements at hot conditions (crankcase temperature above 40 °C).

In contrast, the remaining heat of the main engine body from previous operation, in the lubricating oil drain tank as well as other tanks in the engine room double bottom, is not problematic.
The main engine crankcase temperature must always be added to the measurement records.

[13] Details are given in *DAAD040468 'Guidelines for Measurements'*.
[14] According to the engine-specific drawing of DG 0351 – 'Assembly instructions'.

3.3.2.2 Abortion of measurements

If alignment settings are changed before all measurements of a condition are completed, then the measurements must be aborted immediately.
Subsequently, a waiting time of 6 hours at least are required for the change(s) to become fully effective.
Thereafter, the complete set of measurements of the referred condition must be repeated.

3.4 Recording of bearing load measurement results

Careful recording of bearing load measurement results is essential.
Information about the measurement conditions and the measurement tools must also be included in the records for a clear understanding and a correct judgement of the alignment measurement results.
WinGD provides spreadsheets for recording and evaluation of measurement results (see section *1.2.4*).

3.5 Evaluation of bearing load measurement results

Details about the evaluation of jack-up test measurement results are given in
DAAD040468 'Guidelines for Measurements'.
WinGD provides support according to section *1.2.5*.

3.5.1 Jack correction factors

There are several sources for jack correction factors:

1. a measurement-specific reverse calculation[15]
2. the referred ALC
3. If the referred ALC does not contain jack correction factors for the engine main bearings, then the average jack correction factors given in *Table 3-2* can be applied.

Table 3-2: Average jack correction factors for engine main bearings

Bearing	Jack position	Dial gauge position	Jack correction factor
aftmost mb #1	below flywheel	either on top of flywheel or on top of crankshaft next to the flywheel or on coupling flange next to flywheel	1.6
mb #2 (forward side)	below the aft web of aftmost crank #1	on top of the aft web of aftmost crank #1	1
mb #3 (aft side)	below the forward web of aftmost crank #1	on top of the forward web of aftmost crank #1	1
mb #4 to foremost mb #(n)	below the web next to relevant mb	on top of the web next to relevant mb	1

3.5.1.1 Variation of jack correction factors

A jack correction factor depends on:

1. the position of the jack in relation to the bearings
2. the actual static load distribution of bearings.

Due to different static load distributions, the jack correction factor for most bearings varies only within a range of up to approx. ±0.05.

[15] Applied by WinGD for evaluation of bearing load measurements.

In contrast, the jack correction factor of mb #2 can change significantly, depending on the actual static load distribution of mb #1 and mb #2:

- from approximately 0.8 in cases of a low loaded aftmost mb #1 and a high loaded mb #2
- to approximately 1.3 in cases of a high loaded aftmost mb #1 and a low loaded mb #2.

3.5.2 Tolerances

3.5.2.1 Forward stern tube and intermediate bearings

For the measured static loads of the forward stern tube bearing and the intermediate bearing(s), either the tolerance according to class rules or according to ALC applies – whichever is tighter.
The usual tolerance is ±20%.

3.5.2.2 Engine main bearings

The engine main bearings have the highest sensitivity for offset changes, especially the two aftmost main bearings. Therefore, the above-mentioned tolerance usually applied for the measured static loads of the shaft bearings cannot be applied for main bearings as well.
However, the static load distribution of the three aftmost main bearings measured during installation need to be similar, like in the ALC.

3.6 Recommended static loads for alignment layout calculations of new ship builds

3.6.1 Referred conditions

The recommended static loads for alignment layout calculations of new ship builds, given in *Table 3-3 below*, refer to the general measurement conditions specified in section *3.3.2* and are additional to the following conditions:

1. The manufacture of the ship hull and its superstructure(s), including all main welding works, has been completed.
2. The ship is in a stopped condition and floating continuously, with light ballast to ballast draught.
3. The propulsion plant has ambient temperatures, this comprises:
    a. the main engine
    b. the intermediate bearing support(s)
    c. the double bottom with the main engine foundation and its integrated main engine
    d. lubricating oil drain tank.

3.6.2 Validity

The recommended static loads for alignment layout calculations of new ship builds apply only to calculations that consider the following:

1. main bearings with elastic supports and clearance according to section *2*
2. distribution of static loads on the three aftmost main bearings according to section *3.2*
3. the conditions specified above.

The recommended static loads for layout calculations are given for guidance only, but not as limits. They do not apply to any measurements.

3.6.3 Recommended static load ranges for aftmost mb #1

To enable the consideration of the major factors influencing the advisable static load distribution of the three aftmost engine main bearings, the recommended static loads for aftmost mb #1 are provided as ranges. However, these ranges are neither limit values nor recommended tolerance ranges.

3.6.3.1 Lower part of recommended range

The more the following influences apply, the lower the recommended static bearing load on aftmost mb #1:

1. a large difference of approximately 10m or more between the light ballast or ballast draught during final alignment and the maximum draught in normal ship service, e.g. very large crude carriers (VLCCs) and very large bulk carriers (VLOCs)
2. a short distance between the foremost intermediate bearing and aftmost mb #1, i.e. near the WinGD recommended minimum distance of $0.5 * 450 * \sqrt{Ø_{shaft(mean)}}$ for shaft bearings or even lower
3. a light flywheel.

If all three of the above-mentioned influences apply, then the lowest value of the range is recommended.

3.6.3.2 Upper part of recommended range

The more the following influences apply, the higher the recommended static bearing load on aftmost mb # 1:

1. a small difference of just approximately 6m or less between the light ballast or ballast draught during final alignment and the maximum draught in normal ship service, e.g. gas tankers, vehicle carriers, RoRo vessels and livestock carriers
2. a large distance between the foremost intermediate bearing and aftmost mb #1, i.e. near the WinGD recommended maximum distance for shaft bearings or even higher
3. a heavy flywheel.

If all three of the above-mentioned influences apply, then the highest value of the range is recommended.

3.6.3.3 Designs with no forward stern tube bearing

For designs with no forward stern tube bearing and just one intermediate bearing, an increased static load for the aftmost mb # 1 as listed in the notes of *Table 3-3 below* is strongly recommended.

3.6.4 Data table

Table 3-3: **Recommended static loads for alignment layout calculations of new ship builds cold - stopped condition, light ballast to ballast draught**
Contact WinGD (TechLicSupport@wingd.com) in case of questions about an engine type.

Engine	Var.	aftmost mb #1 [kN]	mb #2 [kN]	mb #3 [kN]	mb #4 to foremost mb #(n) [kN]
X35 X35-B		10 – 20*1	≥ 25	≥ 30	≥ 12
X40 X40-B X40DF X40DF-1.0		12 – 25*2	≥ 40	≥ 40	≥ 15
RT-flex50-D RT-flex50DF		15 – 45*3	≥ 65	≥ 75	≥ 30
X52-S2.0 X52DF-S1.0 X52DF-S2.0 X52DF-M-S1.0	short stroke	15 – 50*3	≥ 70	≥ 80	≥ 30
X52 X52-1.1 X52DF X52DF-1.1 X52DF-2.1 X52DF-A-1.0		15 – 55*3	≥ 80	≥ 95	≥ 35
RT-flex58T-E		20 – 65*3	≥ 100	≥ 110	≥ 40
X62-S2.0 X62DF-S1.0 X62DF-S2.0 X62DF-M-S1.0	short stroke	20*4 – 70	≥ 105	≥ 125	≥ 45
X62 X62-B X62-1.1 X62DF X62DF-1.1 X62DF-2.1 X62DF-1.2 X62DF-2.2 X62DF-A-1.0 X62DF-M-1.0		20*4 – 80	≥ 130	≥ 140	≥ 50

Table 3-3:		Recommended static loads for alignment layout calculations of new ship builds cold - stopped condition, light ballast to ballast draught Contact WinGD (TechLicSupport@wingd.com) in case of questions about an engine type.			
Engine	Var.	aftmost mb #1 [kN]	mb #2 [kN]	mb #3 [kN]	mb #4 to foremost mb #(n) [kN]
X72 X72-B X72DF X72DF-1.1 X72DF-2.1 X72DF-1.2 X72DF-2.2 X72DF-A-1.0		30*4 – 120	≥ 200	≥ 220	≥ 70
X82-2.0 X82DF-1.0 X82DF-2.0 X82DF-M-1.0		40*5 – 140	≥ 300	≥ 280	≥ 100
X92 X92-B X92-1.1 X92DF X92DF-2.0 X92DF-M-1.0		60*5 – 170	≥ 390	≥ 370	≥ 130

Notes of table:

For designs with no forward stern tube bearing and just one intermediate bearing, increased static loads are strongly recommended for aftmost mb # 1:
*1: 20 – 30kN
*2: 25 – 35kN
*3: 40 – 70kN
*4: ≥ 60kN
*5: ≥ 80kN

3.7 Recommended static loads before chocking in new ship builds

The alignment of the propulsion shafts and the main engine is usually carried out according to the data of the cold, stopped condition of the case-specific ALC (see also section *1.3.2*).
Information on static bearing load measurements, recordings and evaluations is provided in sections *1.3.3*, *3.3*, *3.4* and *3.5*.

3.7.1 Referred conditions

The recommended static loads before chocking in new ship builds, given in *Table 3-4 below*, refer to the general measurement conditions specified in section *3.3.2* and additionally to the conditions specified in section *3.6.1* for ALCs.
Any deviation therefrom must be added to the measurement records.
Furthermore, the following is mandatory:

1. The main engine must be supported by the full number of jack screws (or alignment wedges), according to the engine-specific drawings of DG 9710-01 –'Tool engine alignment'.
2. All heat sources that supply the machinery foundation must be switched off in good time before starting measurements according to section *3.3.2.1.*

3.7.2 Validity

The recommended static loads before chocking in new ship builds apply to the conditions specified above.
The recommended static loads before chocking are given for guidance only, but not as limits.
They do not apply to the following measurements:

1. on test bed
2. after chocking and before ship commissioning / delivery (see section *3.8.2*)
3. at ship commissioning / delivery
4. in normal ship service.

3.7.3 Judgement of measured static loads

Alignment is optimum if the static load distribution of the three aftmost engine main bearings complies with the ALC (see section *3.5.2.2*).
In cases of standard ship designs as described in section *1.1.2.1*, the engine alignment is still acceptable if the recommended static loads before chocking in new ship builds are at least met.
If they are not met, or in the case of non-standard designs, WinGD must be contacted for support.

3.7.4 Recommended static load ranges for aftmost mb #1

For designs with no forward stern tube bearing and just one intermediate bearing, an increased static load for the aftmost mb # 1 is strongly recommended, as listed in the notes of *Table 3-4 below*.

3.7.5 Data table

Table 3-4: **Recommended static loads before chocking in new ship builds cold - stopped condition, light ballast to ballast draught**
Contact WinGD (TechLicSupport@wingd.com) in case of questions about an engine type.

Engine	Var.	aftmost mb #1 [kN]	mb #2 [kN]	mb #3 [kN]	mb #4 to foremost mb #(n) [kN]
X35 X35-B		10 – 25*1	≥ 20	≥ 15	≥ 10
X40 X40-B X40DF X40DF-1.0		12 – 30*2	≥ 30	≥ 20	≥ 15
RT-flex50-D RT-flex50DF		15 – 50*3	≥ 55	≥ 45	≥ 20
X52-S2.0 X52DF-S1.0 X52DF-S2.0 X52DF-M-S1.0	short stroke	15 – 55*3	≥ 60	≥ 50	≥ 20
X52 X52-1.1 X52DF X52DF-1.1 X52DF-2.1 X52DF-A-1.0		15 – 60*3	≥ 70	≥ 55	≥ 25
RT-flex58T-E		20 – 75*3	≥ 80	≥ 65	≥ 30
X62-S2.0 X62DF-S1.0 X62DF-S2.0 X62DF-M-S1.0	short stroke	20*4 – 80	≥ 90	≥ 75	≥ 35
X62 X62-B X62-1.1 X62DF X62DF-1.1 X62DF-2.1 X62DF-1.2 X62DF-2.2 X62DF-A-1.0 X62DF-M-1.0		20*4 – 90	≥ 110	≥ 85	≥ 40

Table 3-4:	Recommended static loads before chocking in new ship builds cold - stopped condition, light ballast to ballast draught Contact WinGD (TechLicSupport@wingd.com) in case of questions about an engine type.				
Engine	Var.	aftmost mb #1 [kN]	mb #2 [kN]	mb #3 [kN]	mb #4 to foremost mb #(n) [kN]
X72 X72-B X72DF X72DF-1.1 X72DF-2.1 X72DF-1.2 X72DF-2.2 X72DF-A-1.0		20*4 – 130	≥ 160	≥ 120	≥ 55
X82-2.0 X82DF-1.0 X82DF-2.0 X82DF-M-1.0		30*5 – 160	≥ 230	≥ 160	≥ 80
X92 X92-B X92-1.1 X92DF X92DF-2.0 X92DF-M-1.0		40*5 – 200	≥ 300	≥ 210	≥ 110

Notes of table:

For designs with no forward stern tube bearing and just one intermediate bearing, increased static loads are strongly recommended for aftmost mb # 1:
*1: 20 – 35kN
*2: 25 – 40kN
*3: 40 – 80kN
*4: ≥ 60kN
*5: ≥ 80kN

3.8 Required static loads at ship commissioning / delivery

The required static loads at ship commissioning / delivery apply to measurements made during or after the sea trial of a new ship build.
Information on static bearing load measurements, recordings and evaluations is provided in sections *1.3.3*, *3.3*, *3.4* and *3.5*.

3.8.1 Referred conditions

The required static loads at ship commissioning / delivery, given in *Table 3-5 below*, refer to the general measurement conditions specified in section *3.3.2* and are additional to the following conditions:

1. The ship is completely built and ready for sea trial / operation.
2. The installation of the stern tube and its bearing(s) is completed, the intermediate bearing(s) and the main engine are chocked and fixed to their foundations.
3. The ship is in a stopped condition and floating continuously, with light ballast to ballast draught.
4. The propulsion plant is at cold, warm or hot condition.

Any deviation therefrom must be added to the measurement records.

3.8.2 Validity

The required static loads at ship commissioning / delivery apply to the conditions specified above. In addition, they can also be applied to additional measurements made after chocking and before ship commissioning / delivery.
However, if the ship has not been at sea before, then the tolerance range must not be fully exploited.
In such cases, reserves are needed to avoid the development of inadmissible values due to subsequent settling effects and the release of welding stress.
The required static loads at ship commissioning / delivery do not apply to the following measurements:

1. on test bed
2. before chocking
3. at full draught condition (see section 3.9.2)
4. in normal ship service.

3.8.3 Designs with no forward stern tube bearing

For designs with no forward stern tube bearing and just one intermediate bearing, an increased static load for the aftmost mb # 1 is strongly recommended, as listed in the notes of *Table 3-5 below*.

3.8.4 Data table

Table 3-5	Required static loads at ship commissioning / delivery cold -, warm - or hot - stopped condition, light ballast to ballast draught Contact WinGD (TechLicSupport@wingd.com) in case of questions about an engine type.				
Engine	Var.	aftmost mb #1 [kN]	mb #2 [kN]	mb #3 [kN]	mb #4 to foremost mb #(n) [kN]
X35 X35-B		≥ 8*1	≥ 15	≥ 15	≥ 10
X40 X40-B X40DF X40DF-1.0		≥ 10*2	≥ 25	≥ 20	≥ 15
RT-flex50-D RT-flex50DF		≥ 10*3	≥ 45	≥ 40	≥ 20
X52-S2.0 X52DF-S1.0 X52DF-S2.0 X52DF-M-S1.0	short stroke	≥ 10*3	≥ 50	≥ 45	≥ 20
X52 X52-1.1 X52DF X52DF-1.1 X52DF-2.1 X52DF-A-1.0		≥ 10*3	≥ 55	≥ 50	≥ 25
RT-flex58T-E		≥ 15*3	≥ 70	≥ 50	≥ 30
X62-S2.0 X62DF-S1.0 X62DF-S2.0 X62DF-M-S1.0	short stroke	≥ 15*4	≥ 75	≥ 65	≥ 35
X62 X62-B X62-1.1 X62DF X62DF-1.1 X62DF-2.1 X62DF-1.2 X62DF-2.2 X62DF-A-1.0 X62DF-M-1.0		≥ 15*4	≥ 85	≥ 75	≥ 40

Table 3-5	Required static loads at ship commissioning / delivery cold -, warm - or hot - stopped condition, light ballast to ballast draught Contact WinGD (TechLicSupport@wingd.com) in case of questions about an engine type.				
Engine	**Var.**	**aftmost mb #1** **[kN]**	**mb #2** **[kN]**	**mb #3** **[kN]**	**mb #4 to foremost mb #(n)** **[kN]**
X72 **X72-B** **X72DF** **X72DF-1.1** **X72DF-2.1** **X72DF-1.2** **X72DF-2.2** **X72DF-A-1.0**		≥ 15*4	≥ 130	≥ 110	≥ 55
X82-2.0 **X82DF-1.0** **X82DF-2.0** **X82DF-M-1.0**		≥ 20*5	≥ 200	≥ 150	≥ 80
X92 **X92-B** **X92-1.1** **X92DF** **X92DF-2.0** **X92DF-M-1.0**		≥ 30*5	≥ 260	≥ 190	≥ 110

Notes of table:

For designs with no forward stern tube bearing and just one intermediate bearing, increased static loads are strongly recommended for aftmost mb # 1:

*1: ≥ 16kN
*2: ≥ 20kN
*3: ≥ 30kN
*4: ≥ 40kN
*5: ≥ 60kN

3.9 Minimum limits for static loads for normal ship service

After ship delivery, jack-up tests of engine main bearings are only required in special/exceptional cases as explained in section *1.4*.
Information on static bearing load measurements, recordings and evaluations is provided in sections *1.3.3*, *3.3*, *3.4* and *3.5*.

3.9.1 Referred conditions

The minimum limits for static loads for normal ship service, given in *Table 3-6 below*, refer to the general measurement conditions specified in section *3.3.2* and are additional to the following conditions:

1. The ship is in normal service condition, stopped and ready for operation.
2. The ship is floating continuously, with any draught and trim within the limits of normal ship service, i.e. between light ballast draught and maximum draught.
3. The propulsion plant is at cold, warm or hot condition.

Any deviation therefrom must be added to the measurement records.

3.9.2 Validity

The minimum limits for static loads for normal ship service apply to the conditions specified above.
In addition, they can also be applied to measurements made at full draught condition at ship commissioning / delivery.
However, if the ship has not been at sea before, then the tolerance range must not be fully exploited.
In such cases, reserves are needed to avoid the development of inadmissible values due to subsequent settling effects and the release of welding stress.
The minimum limits for static loads for normal ship service do not apply to the following measurements:

1. on test bed
2. before chocking
3. at ship commissioning / delivery at light ballast or ballast draught condition (see section *3.8.2*).

3.9.3 Designs with no forward stern tube bearing

For designs with no forward stern tube bearing and just one intermediate bearing, the minimum limit for static load at the aftmost mb # 1 is double the value given in *Table 3-6 below*.

3.9.4 Data table

Table 3-6:		Minimum limits for static loads for normal ship service cold -, warm - or hot - stopped condition, light ballast to maximum draught	
Engine	Var.	aftmost mb #1 [kN]	mb #2 to foremost mb #(n) [kN]
X35 X35-B		≥ 5	≥ 10
X40 X40-B X40DF X40DF-1.0		≥ 7	≥ 15
RT-flex50-D RT-flex50DF		≥ 10	≥ 20
X52-S2.0 X52DF-S1.0 X52DF-S2.0 X52DF-M-S1.0	short stroke	≥ 10	≥ 20
X52 X52-1.1 X52DF X52DF-1.1 X52DF-2.1 X52DF-A-1.0		≥ 10	≥ 25
RT-flex58T-E		≥ 15	≥ 30
X62-S2.0 X62DF-S1.0 X62DF-S2.0 X62DF-M-S1.0	short stroke	≥ 15	≥ 35
X62 X62-B X62-1.1 X62DF X62DF-1.1 X62DF-2.1 X62DF-1.2 X62DF-2.2 X62DF-A-1.0 X62DF-M-1.0		≥ 15	≥ 40

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Table 3-6: Minimum limits for static loads for normal ship service cold -, warm - or hot - stopped condition, light ballast to maximum draught			
Engine	Var.	aftmost mb #1 [kN]	mb #2 to foremost mb #(n) [kN]
X72 X72-B X72DF X72DF-1.1 X72DF-2.1 X72DF-1.2 X72DF-2.2 X72DF-A-1.0		≥ 15	≥ 55
X82-2.0 X82DF-1.0 X82DF-2.0 X82DF-M-1.0		≥ 15	≥ 80
X92 X92-B X92-1.1 X92DF X92DF-2.0 X92DF-M-1.0		≥ 20	≥ 110

4 Crank web deflections

4.1 Introduction

The measurement of crank web deflections is the common and well-established method to check the crankshaft alignment (see also section *1.3.3.1*).
The deflection of each crank depends on the vertical and horizontal offsets of its main bearing journals, on aft and forward side of the crank.
The offsets of the main bearing journals result from the machining of the bedplate, the bearing shells, and the crankshaft, as well as from the static loads at each main bearing.
In addition to the above mentioned, external loads acting at both ends of the crankshaft have the following influences:

- In way of the two aftmost cranks, the offsets of main bearing journals depend also on the flange load induced by the direct-coupled propeller and intermediate shafts (see section *3.2*).
- In way of the two foremost cranks, the offsets of main bearing journals depend also on the loading of the forward flange, e.g. if a front disc or a TV damper and/or a free end PTO drive is attached.

A proper alignment of the crankshaft is indicated by crank web deflections being within limits.
If crank web deflection limits are exceeded, then further checks and investigation are required to find the root cause and decide about remedial measures:

1. during installation as described in section 4.5.3
2. as well as in normal ship service as described in section *1.4.*

4.2 Crank web deflection measurements

Wide experience and great care are essential to measure crank web deflections.
Detailed information on this subject is given in *DAAD040468 'Guidelines for Measurements'*.

4.2.1 Tools

The dial gauge must be fully functional and with a smoothly sliding rod. The extension rods required to insert the dial gauge between the crank webs must be firmly hand-tightened during assembly.

4.2.2 Turning direction for measurement

The turning direction during crank web deflection measurement has an influence on the results[16].
WinGD therefore recommends the direction of rotation to measure the crank web deflections depending on the position of the turning gear:

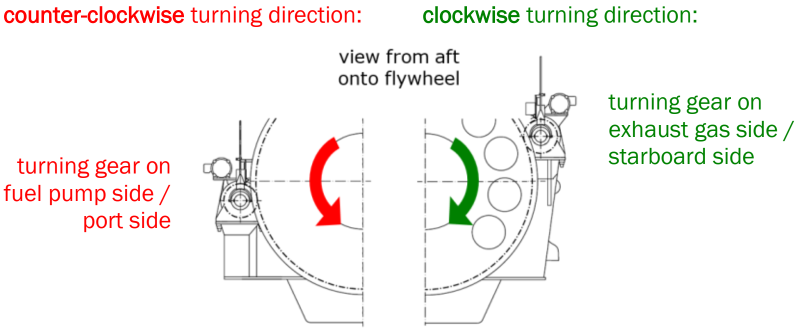


Figure 4-1: Recommended turning direction during crank web deflection measurement

16 In contrast, the working direction of the propeller has no influence on the measurement results.

During a measurement session, the same turning direction must be applied for the web deflection measurement of all cranks, i.e.:

- either for all cranks clockwise
- or for all cranks counter-clockwise.

4.2.3 Measurement positions

The deflection of each crank web is measured at the five turning angle positions illustrated in *Figure 4-2*. The first and the last turning angle position must be located with the dial gauge very close to the connecting rod:

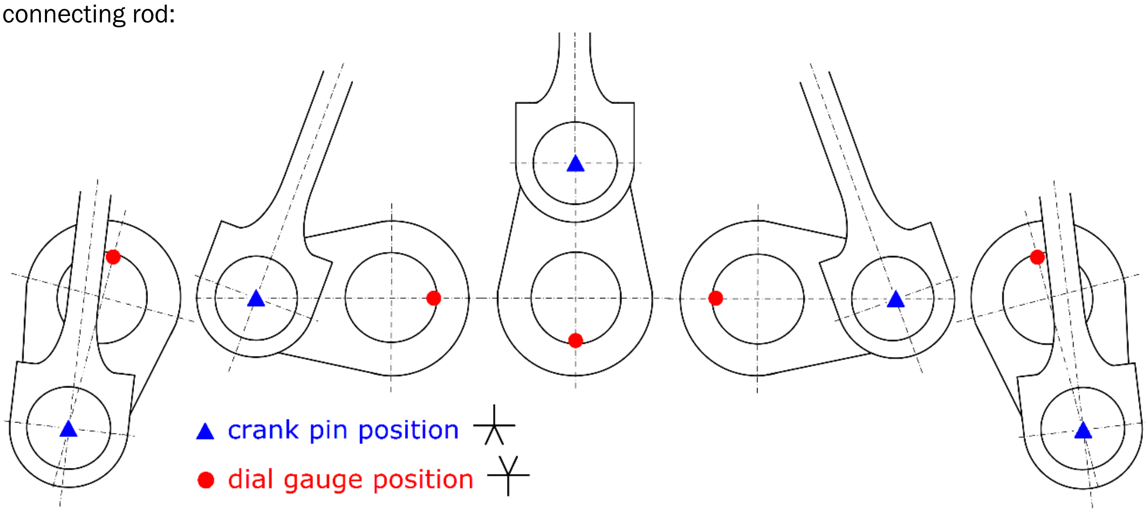


Figure 4-2: Reading positions for crank web deflection measurements

4.2.4 Measurement accuracy

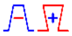
Right after reading the fifth deflection value of each crank, the difference between the first and the fifth crank web deflection reading value must be checked, corresponding to the leftmost and to the rightmost illustrations shown in *Figure 4-2*.
If the engine-specific 'maximum permissible difference between first and last deflection reading value of a crank web' listed in *Table 4-1* is exceeded, then the measurement is questionable and must therefore be repeated[17].

Table 4-1	**Maximum permissible difference between first and last deflection reading value of a crank web**
Engine bore size	**[mm]**
Ø35 to Ø40cm	0.03
Ø50 to Ø62 cm	0.04
Ø72cm	0.05
Ø82 to Ø92 cm	0.06

17 *DAAD040468 'Guidelines for Measurements'* provides detailed information about crank web deflection measurement procedure.

4.3 Recording and evaluation of crank web deflection measurement results

Pre-requisites for a reliable analysis of measurement results are the following:

1. the careful measurement and reading of the crank web deflection and the accurate recording thereof
2. the complete and clear information about the measuring equipment used as well as the boundary conditions found during the measurement, such as:
   a. the reading convention of the dial gauge, i.e.
      i. either  (default in WinGD documentation)
      ii. or 
   b. b. the reading positions referred to (see *Figure 4-2 above*), i.e.
      i. either crank pin positions
      ii. or dial gauge positions
   c. the turning direction for measurement
   d. the engine crankcase temperature
   e. the forward and aft ship draught.

WinGD provides spreadsheets for recording and evaluation of alignment measurement results (see section *1.2.4*).
More details about recording and manual evaluation of crank web deflection measurement results are given in *DAAD040468 'Guidelines for Measurements'*.

4.4 Crank web deflection limits on test bed

The crank web deflections of the completed engine, measured on test bed in un-coupled cold condition, are a binding requirement for engine approval.
They are also the reference for subsequent installation in the ship.
If final measurements exceed the limits, then WinGD must be informed.
Information on crank web deflection measurements, recordings and evaluations are provided in sections *1.3.3*, *4.2* and *4.3*.

4.4.1 Referred conditions

The crank web deflection limits on test bed, given in *Table 4-2 below*, refer to the following conditions:

1. The main engine is completely assembled, with all pistons and running gears installed as well as all tie rods fully tightened[12].
2. The flywheel is installed and, if specified by the separate TVC for the test bed, also the front disc (tuning wheel) or the TV damper.
3. In un-coupled condition
   a. the crankshaft aft end flange is un-coupled from the connecting shaft to the water brake.
   b. the engine is at cold condition.
4. In coupled condition
   a. all coupling bolts of the connecting shaft (water brake to engine) are fully tightened.
   b. the engine and the water brake are at cold condition.
   c. the engine and the water brake are fixed to their foundation and ready for the test run.
5. The engine is in a stopped condition.

Any deviation therefrom must be added to the measurement records.

4.4.2 Validity

The crank web deflection limits on test bed apply to the conditions specified above.
They do not apply to the following measurements:

1. on testbed in hot condition of the engine (see section *4.5.2*)
2. any measurements made in the ship.

4.4.3 Data table

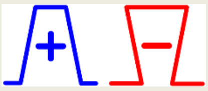
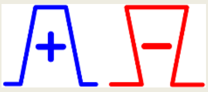
Table 4-2: Crank web deflection limits on test bed							
deflections		vertical					horizontal
sign convention:		aftmost crank #1		inner cranks	foremost crank #(n)		all cranks
		un-coupled*1	coupled to brake		no external mass*2 at fwd end	with external mass*3 at fwd end	
Engine	Var.	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
X35 X35-B		0.11 -0.25	0.11 -0.11	0.11 -0.11	0.11 -0.11	0.11 -0.27	0.06 -0.06
X40 X40-B X40DF X40DF-1.0		0.13 -0.29	0.13 -0.13	0.13 -0.13	0.13 -0.13	0.13 -0.32	0.07 -0.07
RT-flex50-D RT-flex50DF		0.17 -0.38	0.17 -0.17	0.17 -0.17	0.17 -0.17	0.17 -0.42	0.09 -0.09
X52-S2.0 X52DF-S1.0 X52DF-S2.0 X52DF-M-S1.0	short stroke	0.17 -0.38	0.17 -0.17	0.17 -0.17	0.17 -0.17	0.17 -0.42	0.09 -0.09
X52 X52-1.1 X52DF X52DF-1.1 X52DF-2.1 X52DF-A-1.0		0.18 -0.41	0.18 -0.18	0.18 -0.18	0.18 -0.18	0.18 -0.45	0.10 -0.10
RT-flex58T-E		0.23 -0.53	0.23 -0.23	0.23 -0.23	0.23 -0.23	0.23 -0.58	0.12 -0.12
X62-S2.0 X62DF-S1.0 X62DF-S2.0 X62DF-M-S1.0	short stroke	0.22 -0.49	0.22 -0.22	0.22 -0.22	0.22 -0.22	0.22 -0.54	0.11 -0.11
X62 X62-B X62-1.1 X62DF X62DF-1.1 X62DF-2.1 X62DF-1.2 X62DF-2.2 X62DF-A-1.0 X62DF-M-1.0		0.22 -0.51	0.22 -0.22	0.22 -0.22	0.22 -0.22	0.22 -0.56	0.12 -0.12

Table 4-2:		Crank web deflection limits on test bed					
deflections		vertical					horizontal
sign convention:		aftmost crank #1		inner cranks	foremost crank #(n)		all cranks
		un-coupled*1	coupled to brake		no external mass*2 at fwd end	with external mass*3 at fwd end	
Engine	Var.	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
X72 X72-B X72DF X72DF-1.1 X72DF-2.1 X72DF-1.2 X72DF-2.2 X72DF-A-1.0		0.32 -0.74	0.32 -0.32	0.32 -0.32	0.32 -0.32	0.32 -0.82	0.17 -0.17
X82-2.0 X82DF-1.0 X82DF-2.0 X82DF-M-1.0		0.35 -0.82	0.35 -0.35	0.35 -0.35	0.35 -0.35	0.35 -0.90	0.18 -0.18
X92 X92-B X92-1.1 X92DF X92DF-2.0 X92DF-M-1.0		0.42 -0.98	0.42 -0.42	0.42 -0.42	0.42 -0.42	0.42 -1.08	0.22 -0.22

Notes of table:

*1: The crankshaft aft end flange is un-coupled from the connecting shaft to the water brake.
*2: For engines without front disc (tuning wheel), TV damper and/or free end PTO drive.
*3: For engines with front disc (tuning wheel) or TV damper and/or free end PTO drive.

4.5 Crank web deflection limits before chocking in new ship builds

The alignment of the propulsion shafts and the main engine is usually carried out according to the data of the cold, stopped condition of the case-specific ALC (see also section *1.3.2*).
Information on crank web deflection measurements, recording and evaluation is provided in sections *1.3.3*, *4.2* and *4.3*.

4.5.1 Referred conditions

The crank web deflection limits before chocking in new ship builds, given in *Table 4-3 below*, refer to the general measurement conditions specified in section *3.3.2* and are additional to the same conditions as specified in section *3.7.1* for recommended static loads before chocking in new ship builds.
Any deviation therefrom must be added to the measurement records.
In addition, they can also be applied to measurements made on testbed in hot condition of the engine.

4.5.2 Validity

The crank web deflection limits before chocking in new ship builds apply to the conditions specified above.
They do not apply to the following measurements:

1. on test bed at cold condition of the engine and the water brake
2. after chocking and before ship commissioning / delivery (see section *4.6.2*)
3. at ship commissioning / delivery
4. in normal ship service.

4.5.3 Threshold value for deviation of vertical web deflections between neighbouring cranks

The greater the difference between the vertical crank web deflections of any two neighbouring cranks, the greater the risk that there is a lack of static load on a main bearing near them.
The engine-specific threshold value indicates such states:

1. If the difference of measured vertical web deflections of two neighbouring cranks exceeds the threshold value given in *Table 4-3 below*, then the static loads of the main bearings next to these neighbouring cranks must also be measured.
2. If the static loads of the main bearings next to these two neighbouring cranks are within limits, then the increased difference in vertical web deflections of these cranks can also be accepted, otherwise re-adjustments are necessary.

IMPORTANT:
The engine-specific ‘threshold value for the deviation of vertical web deflections of neighbouring cranks’ is not a final acceptance criterion.
It just indicates whether the static loads of the main bearings next to these neighbouring cranks need also be checked.

4.5.3.1 Threshold value exceeded at the two aftmost cranks

The ‘threshold value for the deviation of vertical web deflections of any two neighbouring cranks’ can be exceeded at the two aftmost cranks #1 and #2, especially on a cold engine with either light ballast or ballast draught.
The requirement according to section *4.5.3* is met if the static loads of the three aftmost engine main bearings are within limits.
If so, this increased difference in vertical crank web deflections of the two aftmost cranks #1 and #2 can also be accepted.

4.5.3.2 Threshold value exceeded at the two foremost cranks

The ‘threshold value for the deviation of vertical web deflections of any two neighbouring cranks’ can be exceeded at the two foremost cranks #(n) and #(n-1) if an external load is attached to the forward end of the crankshaft, for instance a front disc (tuning wheel) or a TV damper and/or a free end PTO drive.
The requirement according to section *4.5.3* is met if the static loads of the two foremost engine main bearings are within limits.
If so, this increased difference in vertical crank web deflections of the two foremost cranks #(n) and #(n-1) can also be accepted.

4.5.3.3 Threshold value exceeded at inner[18] cranks

If the threshold value for the deviation of the vertical web deflections of two adjacent inner cranks is exceeded, then WinGD must be contacted.

[18] Second-aftmost crank #2 to: second-foremost crank #(n-1).

4.5.4 Data table

Table 4-3: Crank web deflection limits before chocking in new ship builds

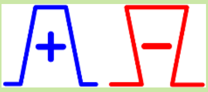
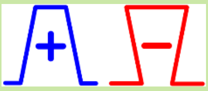
deflections		vertical					horizontal
sign convention:		aftmost crank #1	inner cranks	foremost crank #(n)		all cranks	all cranks
		coupled to propulsion shafts		no external mass*1 at fwd end	with external mass*2 at fwd end	deviation threshold value*3	coupled to propulsion shafts
Engine	Var.	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
X35 X35-B		0.20 -0.15	0.15 -0.15	0.15 -0.15	0.15 -0.27	0.13	0.07 -0.07
X40 X40-B X40DF X40DF-1.0		0.24 -0.18	0.18 -0.18	0.18 -0.18	0.18 -0.32	0.15	0.08 -0.08
RT-flex50-D RT-flex50DF		0.31 -0.23	0.23 -0.23	0.23 -0.23	0.23 -0.42	0.19	0.11 -0.11
X52-S2.0 X52DF-S1.0 X52DF-S2.0 X52DF-M-S1.0	short stroke	0.31 -0.23	0.23 -0.23	0.23 -0.23	0.23 -0.42	0.19	0.11 -0.11
X52 X52-1.1 X52DF X52DF-1.1 X52DF-2.1 X52DF-A-1.0		0.33 -0.25	0.25 -0.25	0.25 -0.25	0.25 -0.45	0.20	0.12 -0.12
RT-flex58T-E		0.42 -0.31	0.31 -0.31	0.31 -0.31	0.31 -0.58	0.26	0.15 -0.15
X62-S2.0 X62DF-S1.0 X62DF-S2.0 X62DF-M-S1.0	short stroke	0.39 -0.29	0.29 -0.29	0.29 -0.29	0.29 -0.54	0.24	0.14 -0.14
X62 X62-B X62-1.1 X62DF X62DF-1.1 X62DF-2.1 X62DF-1.2 X62DF-2.2 X62DF-A-1.0 X62DF-M-1.0		0.40 -0.30	0.30 -0.30	0.30 -0.30	0.30 -0.56	0.25	0.14 -0.14

Table 4-3: Crank web deflection limits before chocking in new ship builds

deflections		vertical					horizontal
sign convention:		aftmost crank #1	inner cranks	foremost crank #(n)		all cranks	all cranks
		coupled to propulsion shafts		no external mass*1 at fwd end	with external mass*2 at fwd end	deviation threshold value*3	coupled to propulsion shafts
Engine	Var.	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
X72 X72-B X72DF X72DF-1.1 X72DF-2.1 X72DF-1.2 X72DF-2.2 X72DF-A-1.0		0.59 -0.44	0.44 -0.44	0.44 -0.44	0.44 -0.82	0.36	0.20 -0.20
X82-2.0 X82DF-1.0 X82DF-2.0 X82DF-M-1.0		0.64 -0.48	0.48 -0.48	0.48 -0.48	0.48 -0.90	0.39	0.22 -0.22
X92 X92-B X92-1.1 X92DF X92DF-2.0 X92DF-M-1.0		0.77 -0.58	0.58 -0.58	0.58 -0.58	0.58 -1.08	0.47	0.26 -0.26

Notes of table:

*1: For engines without front disc (tuning wheel), TV damper and/or free end PTO drive.
*2: For engines with front disc (tuning wheel) or TV damper and/or free end PTO drive.
*3: This value is used to indicate if further investigations are required according to section *4.5.3*, but it is not a limit for final acceptance.

4.6 Crank web deflection limits at ship commissioning / delivery

The crank web deflection limits at ship commissioning / delivery apply to measurements made during or after the sea trial of a new ship build.
Information on crank web deflection measurements, recordings and evaluations is provided in sections *1.3.3*, *4.2* and *4.3.*

4.6.1 Referred conditions

The crank web deflection limits at ship commissioning / delivery, given in *Table 4-4 below*, refer to the general measurement conditions specified in section *3.3.2* and are additional to the same conditions as specified in section *3.8.1* for the required static loads at ship commissioning / delivery.
Any deviation therefrom must be added to the measurement records.

4.6.2 Validity

The crank web deflection limits at ship commissioning / delivery apply to the conditions specified above.
In addition, they can also be applied to measurements made after chocking.
However, if the ship has not been at sea before, then the tolerance range must not be fully exploited.
In such cases, reserves are needed to avoid the development of inadmissible values due to subsequent settling effects and the release of welding stress.
The crank web deflection limits at ship commissioning / delivery do not apply to the following measurements:

1. on test bed
2. before chocking
3. at full draught condition (see section 4.7.2)
4. in normal ship service.

4.6.3 Threshold value for deviation of vertical web deflections between neighbouring cranks

The content of section *4.5.3* is also valid for measurements at ship commissioning / delivery, referring to the deviation threshold values listed in *Table 4-4 below*.

4.6.4 Data table

Table 4-4: Crank web deflection limits at ship commissioning / delivery

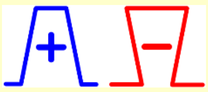
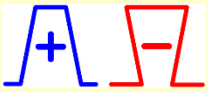
Deflections sign convention:		vertical					horizontal
		aftmost crank #1 coupled to propulsion shafts	inner cranks	foremost crank #(n) no external mass*1 at fwd end	foremost crank #(n) with external mass*2 at fwd end	all cranks deviation threshold value*3	all cranks coupled to propulsion shafts
Engine	Var.	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
X35 X35-B		0.24 -0.27	0.18 -0.18	0.18 -0.18	0.18 -0.27	0.15	0.09 -0.09
X40 X40-B X40DF X40DF-1.0		0.28 -0.32	0.21 -0.21	0.21 -0.21	0.21 -0.32	0.17	0.10 -0.10
RT-flex50-D RT-flex50DF		0.37 -0.42	0.27 -0.27	0.27 -0.27	0.27 -0.42	0.22	0.13 -0.13
X52-S2.0 X52DF-S1.0 X52DF-S2.0 X52DF-M-S1.0	short stroke	0.37 -0.42	0.27 -0.27	0.27 -0.27	0.27 -0.42	0.22	0.13 -0.13
X52 X52-1.1 X52DF X52DF-1.1 X52DF-2.1 X52DF-A-1.0		0.39 -0.45	0.29 -0.29	0.29 -0.29	0.29 -0.45	0.24	0.14 -0.14
RT-flex58T-E		0.50 -0.58	0.37 -0.37	0.37 -0.37	0.37 -0.58	0.30	0.17 -0.17
X62-S2.0 X62DF-S1.0 X62DF-S2.0 X62DF-M-S1.0	short stroke	0.47 -0.54	0.35 -0.35	0.35 -0.35	0.35 -0.54	0.28	0.16 -0.16
X62 X62-B X62-1.1 X62DF X62DF-1.1 X62DF-2.1 X62DF-1.2 X62DF-2.2 X62DF-A-1.0 X62DF-M-1.0		0.48 -0.56	0.36 -0.36	0.36 -0.36	0.36 -0.56	0.29	0.17 -0.17

Table 4-4:	Crank web deflection limits at ship commissioning / delivery						
Deflections		vertical					horizontal
sign convention: 		aftmost crank #1 coupled to propulsion shafts	inner cranks	foremost crank #(n) no external mass*1 at fwd end	foremost crank #(n) with external mass*2 at fwd end	all cranks deviation threshold value*3	all cranks coupled to propulsion shafts
Engine	Var.	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
X72 X72-B X72DF X72DF-1.1 X72DF-2.1 X72DF-1.2 X72DF-2.2 X72DF-A-1.0		0.70 -0.82	0.53 -0.53	0.53 -0.53	0.53 -0.82	0.43	0.24 -0.24
X82-2.0 X82DF-1.0 X82DF-2.0 X82DF-M-1.0		0.77 -0.90	0.58 -0.58	0.58 -0.58	0.58 -0.90	0.47	0.26 -0.26
X92 X92-B X92-1.1 X92DF X92DF-2.0 X92DF-M-1.0		0.92 -1.08	0.69 -0.69	0.69 -0.69	0.69 -1.08	0.56	0.32 -0.32

Notes of table:

*1: For engines without front disc (tuning wheel), TV damper and/or free end PTO drive.
*2: For engines with front disc (tuning wheel) or TV damper and/or free end PTO drive.
*3: This value is used to indicate if further investigations are required according to section *4.5.3*, but it is not a limit for final acceptance.

4.7 Crank web deflection limits for normal ship service

Crank web deflection measurements in normal ship service are carried out according to section *1.4*. Information on crank web deflection measurements, recordings and evaluations is provided in sections *1.3.3*, *4.2* and *4.3*.

4.7.1 Referred conditions

The crank web deflection limits for normal ship service, given in *Table 4-5 below*, refer to the general measurement conditions specified in section *3.3.2* and are additional to the same conditions as specified in section *3.9.1* for the minimum limits for static loads for normal ship service.
Any deviation therefrom must be added to the measurement records.

4.7.2 Validity

The crank web deflection limits for normal ship service apply to the conditions specified above.
In addition, they can also be applied to measurements made at full draught condition at ship commissioning / delivery.
However, if the ship has not been at sea before, then the tolerance range must not be fully exploited.
In such cases, reserves are needed to avoid the development of inadmissible values due to subsequent settling effects and the release of welding stress.
The crank web deflection limits for normal ship service do not apply to the following measurements:

1. on test bed
2. before chocking
3. at ship commissioning / delivery at light ballast or ballast draught condition.

4.7.3 Data table

Table 4-5: Crank web deflection limits for normal ship service

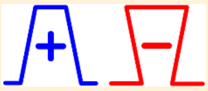
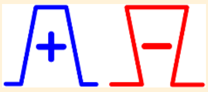
deflections		vertical				horizontal
sign convention: 		aftmost crank #1 coupled to propulsion shafts	inner cranks	foremost crank #(n) no external mass*1 at fwd end	foremost crank #(n) with external mass*2 at fwd end	all cranks coupled to propulsion shafts
Engine	Var.	[mm]	[mm]	[mm]	[mm]	[mm]
X35 X35-B		0.27 -0.27	0.19 -0.19	0.19 -0.19	0.19 -0.27	0.09 -0.09
X40 X40-B X40DF X40DF-1.0		0.32 -0.32	0.23 -0.23	0.23 -0.23	0.23 -0.32	0.11 -0.11
RT-flex50-D RT-flex50DF		0.42 -0.42	0.30 -0.30	0.30 -0.30	0.30 -0.42	0.14 -0.14
X52-S2.0 X52DF-S1.0 X52DF-S2.0 X52DF-M-S1.0	short stroke	0.42 -0.42	0.30 -0.30	0.30 -0.30	0.30 -0.42	0.14 -0.14
X52 X52-1.1 X52DF X52DF-1.1 X52DF-2.1 X52DF-A-1.0		0.45 -0.45	0.32 -0.32	0.32 -0.32	0.32 -0.45	0.15 -0.15
RT-flex58T-E		0.58 -0.58	0.41 -0.41	0.41 -0.41	0.41 -0.58	0.19 -0.19
X62-S2.0 X62DF-S1.0 X62DF-S2.0 X62DF-M-S1.0	short stroke	0.54 -0.54	0.38 -0.38	0.38 -0.38	0.38 -0.54	0.18 -0.18
X62 X62-B X62-1.1 X62DF X62DF-1.1 X62DF-2.1 X62DF-1.2 X62DF-2.2 X62DF-A-1.0 X62DF-M-1.0		0.56 -0.56	0.40 -0.40	0.40 -0.40	0.40 -0.56	0.18 -0.18

Table 4-5: Crank web deflection limits for normal ship service



deflections		vertical				horizontal
sign convention:		aftmost crank #1	inner cranks	foremost crank #(n)		all cranks
		coupled to propulsion shafts		no external mass*1 at fwd end	with external mass*2 at fwd end	coupled to propulsion shafts
Engine	Var.	[mm]	[mm]	[mm]	[mm]	[mm]
X72 X72-B X72DF X72DF-1.1 X72DF-2.1 X72DF-1.2 X72DF-2.2 X72DF-A-1.0		0.82 -0.82	0.58 -0.58	0.58 -0.58	0.58 -0.82	0.27 -0.27
X82-2.0 X82DF-1.0 X82DF-2.0 X82DF-M-1.0		0.90 -0.90	0.64 -0.64	0.64 -0.64	0.64 -0.90	0.29 -0.29
X92 X92-B X92-1.1 X92DF X92DF-2.0 X92DF-M-1.0		1.08 -1.08	0.76 -0.76	0.76 -0.76	0.76 -1.08	0.35 -0.35

Notes of table:

*1: For engines without front disc (tuning wheel), TV damper and/or free end PTO drive.
*2: For engines with front disc (tuning wheel) or TV damper and/or free end PTO drive.